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SOME PECULIARITIES OF THE MAGNETIC FIELD IN THE SOLAR CORONA

by

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(USSR)

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by A. T. Nesmyanovich

ABSTRACT

Several new arguments in favor of the notion of a variable character of solar corona's magnetic field are brought out on the basis of processing of catalogue data on the structural forms of the corona, compiled by the author according to photographic observations of 38 eclipses.

The photometry of polar rays of the corona in 1961 and 1936 and the comparison with similar studies of the corona in 1900, 1914, 1952, 1954 and 1955 show that the ratio of radial to interradial electron concentration ($N_л / N_к$) varies with the phase of solar activity. This makes possible the conclusion on magnetic field intensity variation in polar caps.

A North-South latitude asymmetry in corona structure is recognized from the comparison of the structural forms of the corona for a series of eclipses. This is explained by the asymmetry of the magnetic field in the corona relative to solar equatorial plane.

An assumption is made that the asymmetric properties of the magnetic fields of the Earth and Sun are characteristic of all the bodies of the solar system.

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* Nekotoryye osobennosti magnitnogo polya v solnechnoy korone.

COVER-TO-COVER TRANSLATION

The notion of solar corona structure as being determined by the magnetic field is universally recognized. At the same time it is implied that the magnetic field is an aggregate field, composed of the magnetic field of the Sun, possibly of dipole character, of local fields of active formations and of fields induced in the total field by conducting matter's currents, (see ref [1]). Some well known facts may be brought forth in favor of such a notion :

— a) the existence of a magnetic field of dipole character in the polar regions of the photosphere of ~ 1 oe intensity ;

— b) the coincidence of shapes of polar radial systems with the lines of force of magnetic dipole [3, 4];

— c) the corona structure variation and shape repetition conforming to an established rule;

— d) the stability of coronal formations [1];

— e) the prolonged existence "side by side" of "red" and "green" regions, which may be only conditioned by the presence of magnetic "barriers" [5], and other facts.

As to the basic peculiarities of the magnetic field in the corona and the reasons of its origin, these questions are still insufficiently studied.

Currently, the author has composed a catalogue of structural forms of the corona according to photographs of 38 eclipses. All the drawings are made in a single scale and are characterized by uniformity. A great attention is given to the structure of the outer regions of the corona. The material assembled provides the possibility to derive certain new conclusions on the character of the magnetic field in the corona and to corroborate the earlier representations.

1. VARIABILITY OF THE MAGNETIC FIELD IN THE CORONA

This question was raised by S. K. Vsekhsvyatskiy [6] and then discussed by V. I. Ivanchuk [7]. As to the variability of the total magnetic field of the Sun, it was established by Babcock's observations [2].

On the basis of processing of cataologue data, the variation of the parameters π, H, i_{cp} and others (π being the extent of polar systems along the solar limb, H — the geometrical contraction of the corona accoring to Nikol'skiy [9], i_{cp} *— the mean angle of inclination of the major rays), is brought out in a recently published work by the author [8]. The regular course with the the phase of activity of all the above-enumerated parameters may be explained by the influence of some general factor, which is the broad variable magnetic field of the Sun in the corona. Still more convicing factor corroborating such notion is the variation of the parameter q, characterizing the distance between the poles of the "assumed" magnetic dipole. The latter (q) has been determined as follows : To all polar rays tangents were traced at their bases, which intersected in a certain region on the axis of rotation of the Sun, or with a certain displacement. The distance between these regions, expressed in Sun's diameters, is precisely the parameter q. The mean measurement error constitutes $\pm$ 0.05 $D_{\odot}$. A similar method was earlier utilized by E. Ya. Bugoslavskaya [11], who determined the mean value of $q = 0.57\ D_{\odot}$ according to 10 eclipses.

Having a larger material than that of Bugoslavskaya, it is possible to study the course of the parameter q with the solar activity phase Φ. For that purpose we utilized all the corona drawings where polar radial systems were observed. Altogether 31 drawings were so utilized. The results of measurements are are brought out in Fig. 1 and Table 1.

TABLE 1

Date of Eclipse	Φ	q	r_N	r_S	Π_N	Π_S	Asymmetry corona	Asymmetry synop.map
1	2	3	4	5	6	7	8	9
1871 XII 11	−0.85	0.40	0.43	0.37	25°	20°	Асимм.**	
1878 VI 29	−0.05	0.70	0.79	0.61	70°	75°	(N — S)	
1886 VIII 29	−0.56	0.49					E — W	
1887 VIII 19	−0.41	0.58	0.61	0.55	43°	20°	N — S*	
1889 I 1	−0.18	0.58	0.63	0.53	73	63	Симм.	S — N
1889 XII 21	−0.03	0.69					Симм.	
1893 IV 16	+0.79	0.46					Асимм.	S — N
1896 VIII 8	−0.68	0.51	0.53	0.49	37	35	N — S	S — N
1898 I 21	−0.48	0.63	0.67	0.58	54	46	E — W	
1900 V 28	−0.21	0.68	0.72	0.63	63	53	(E — W)	(S — N)
1901 V 17	−0.07	0.68	0.68	0.68	59	59	Симм.	Симм.
1908 I 3	−0.75	0.49	0.51	0.47	30	30	N — S	S — N
1910 V 8	−0.43	0.60	0.67	0.53	54	54	E — W	
1911 IV 28	−0.31	0.67						
1914 VIII 21	+0.25	0.65	0.65	0.65	54	42	E — W	S — N
1918 VI 8	−0.89	0.51	0.53	0.49	35	45	E — W	
1919 V 29	−0.71	0.54	0.58	0.49	60	35	N — S	(S — N)
1922 IX 20	−0.14	0.65					E — W	
1923 IX 10	+0.04	0.67	0.72	0.63	68	64	E — W	Низ. акт. (low activ.)
1925 I 25	+0.32	0.58	0.63	0.53	60	40	(N — S)	(N — S)
1929 VI 9	−0.80	0.30	0.30	0.30	40	30	(N — S)	Выс. акт. (high activ.)
1930 IV 28	−0.63	0.58	0.51	0.65	65	45	E — W	(N — S)
1932 VIII 31	−0.20	0.63	0.65	0.60	55	75	N—S, E—W	Низ. акт.
1934 II 14	+0.14	0.65					Симм.	Низ. акт.
1936 VI 19	+0.77	0.51	0.56	0.47	30	20	N — S	(S — N)
1937 VI 8	−0.98				30	0	N — S	N — S
1941 IX 21	−0.35	0.65	0.67	63	43	45	E — W	(N — S)
1945 VI 9	+0.25	0.58	0.63	0.54	58	56	E — W	S — N
1952 II 25	−0.36	0.58	0.58	0.58	60	45	E — W	(S — N)
1954 VI 30	0.00	0.67	0.74	0.60	70	72	Симм.	Низ. акт.
1955 VI 20	+0.25	0.60	0.60	60	68	50	Симм.	
1961 II 15	(−0.50)	0.60	0.67	0.54	70	30	N — S	S — N
average		0.58	0.61	0.54	51.2	44.6	N — S	S — N

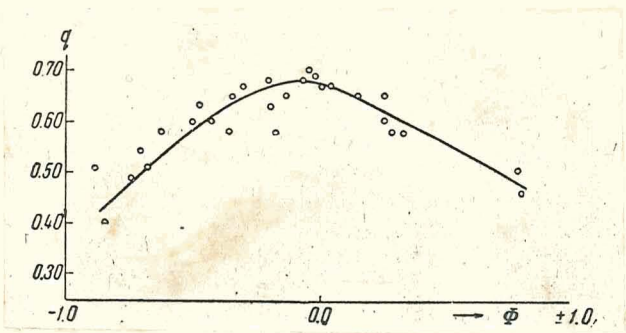

Fig. 1

Асимм. means "ASYMMETRY
Симм. - "SYMMETRY"

2. MAGNETIC FIELD INTENSITY VARIATION IN THE CORONA

We brought in the preceding paragraph a series of deductions in favor of the variable character of the magnetic field in the corona. We shall now attempt to show that the field intensity is also varying with the phase of activity.

The increased electron concentration in polar rays is explained by the "retaining" property of the magnetic field. As is well known, diffusion across the lines of force is extremely low and is dependent upon the magnetic field H intensity as follows : $D \sim 1/H^2$. In such cade, the higher the intensity of the magnetic field in polar caps, the lower is the diffusion and the higher — the electron concentration in the rays.

At the present time the ratios of electron concentrations in the ray to that in the interradial space ($N_л / N_K$) are estimated for the corona of 1900 and 1954 by G. M. Nikol'skiy [12] and for that of 1954 — by N. I. Dzyubenko [13]. These eclipses are related to the minimum epoch. The estimate of such ratio $N_л/N_K$ for a corona near maximum type offers a significant interest. The photometry of corona polar brushes for 1961 and 1936 was conducted to that effect.

The photograph of the corona of 15 February 1961 was obtained with the aid of a 5-meter coronograph of the expedition by the Kiev division of the All-Union Astronomo-Geodesical Society [14] on an Isopan ISS photoplate with a 5 sec.exposure. The negative of the corona was measured out on a self-registering microphotometer МФ-4. The photometrical cuts were made perpendicularly to Sun's rotation axis, at every millimeter in the northern polar region. Seven rays were thus separated in all. Two of the brightests rays were selected for the final processing, upon which no other rays apparently superimposed. The results of such measurements and calculations are brought out in Table 2.

TABLE 2

Ray 1, $\varphi = +78$, sector EN				Ray 2, $\varphi = +83$, sector EN			
ρ	Δ	$I_Л/I_К$	$N_Л/N_К$	ρ	Δ	$I_Л/I_К$	$N_Л/N_К$
1.16	0.077	0.32	5.2	1.12	0.060	0.40	7.6
1.20	0.060	0.19	4.4	1.16	0.064	0.35	6.6
1.24	0.060	0.17	4.1	1.20	0.072	0.31	5.5
1.31	0.060	0.18	4.4	1.26	0.080	0.22	4.1

In the column 1 of Table 2 are given the distances from the center of the Sun to the point of measurement in $R_\odot$. In the column 2 are brought out the values of the visible width or of the photometrical half-width of the ray Δ. The ray to corona brightness surfaces' ratio in the interval between the rays — $I_Л/I_К$, is possibly beset with some errors. This may be conditioned by the failure to account for the Fraunhofer component, and by the insufficient accounting of the scattered light. It was assumed in the given case that the course of scattered light in the corona is the same as on the lunar disk near the limb. This overrates somewhat the value of $I_Л/I_К$. It may however be shown that these errors are insignificant for the inner corona and that they cannot substantially distort the results.

In the column 4 are given the electron concentrations' ratios which were calculated according to formula given in ref. [12]:

$$\frac{N_Л}{N_К} = \frac{I_Л}{I_К} \frac{\pi}{n \int_0^{\pi/2} \sin^n \varphi d\varphi} \frac{\rho}{\Delta} + 1;$$

Here n is the index in the exponential law of brightness surface variations. After taking into account the background, the law in our case had the form:

$$I(r) = I_0 \rho^{-n},$$

where $n = 8$.

Using an analogus method, we processed the corona photograph of 19 June 1936. The negative was obtained by means of a standard coronograph by Svekhsvyatskiy and V. F. Gaze [15] using a Special Rapid plate with a 6 sec. exposure. Two brightest rays were selected also in the north polar system. The scattered light was insignificant, and its accounting was not made. The index n for the 1.04 — 1.3 distance interval is 6.2.

TABLE 3

Ray 1, φ = + 82. sector WN				Ray 2, φ = + 86° sect. WN		
ρ	Δ	$I_Л/I_К$	$N_Л/N_К$	Δ	$I_Л/I_К$	$N_Л/N_К$
104	0.030	0.12	5.4	0.030	0.12	5.4
109	0.034	0.12	5.0	0.034	0.12	5.0
1.13	0.034	0.12	5.2	0.034	0.12	5.2
1.18	0.039	0.12	4.8	0.034	0.10	4.7
1.22	0.039	0.10	4.2	0.039	0.10	4.2
126	0.039	0.10	4.4	0.039	0.10	4.4
1.31	0.043	0.10	4.1	0.039	0.10	4.1

Presented are in Table 3 the results of computations and measurements by the negative of the 1936 corona.

In order to derive the variation of the ratio $N_Л/N_К$ with the phase of activity, we brought out in Table 4 the mean values of such ratios for all the eclipses for which investigations were made.

The ratio $N_Л/N_К$ for the corona of 25 February 1952 was determined by L. N. Kurochka in cooperation with the author [27] on the basis of a photograph obtained by Nikol'skiy [16]. The ratio $N_Л/N_К$ for the 1914 corona was computed according to data on $I_Л/I_К$ and Δ borrowed from the work by Bugoslavskaya [17].

As may be seen from Table 4, the mean ratio $N_Л/N_К$ varies with the phase of activity. This provides the possibility to speak

about the variation of magnetic field intensity in the corona. At the same time field intensity decreases during the period of solar activity maximum, since electron concentration in polar rays diminishes.

TABLE 4

Date of Eclipse	Φ	ρ	$N_{\text{П}}/N_{\text{К}}$	Reference source
1954	0.00	1.25	7.9	[13]
1954		1.31—1.52	7.0	[12]
1900	—0.21	1.2	11	[12]
1914	+0.25	1.1	9	[17]
1952	—0.37	1.36	7.1	[27]
1961	(—0.50)	1.12—1.31	5.4	[27]
1936	+0.77	1.18—1.31	4.4	[27]

3. NORTH-SOUTH LATITUDE ASYMMETRY OF CORONA'S MAGNETIC FIELD

Comparison of the corona drawings for a series of eclipses points to a North-South latitude asymmetry in the corona structure, which consists in the following: Better developed polar radial systems and more sharply expressed large fan rays are more often observed in the Northern hemisphere. In the Southern hemisphere polar radial systems are in such cases slightly developed or altogether absent. The large rays are either straight or have fans of small extent. Such asymmetry is characteristic for a corona of maximum and intermediate type. Most representative in this regard are are drawings of the 1896, 1908, 1919, 1936 and 1961 coronas. Cases of opposite asymmetry, i.e. when the structure of the Southern hemisphere would be more developed are not encountered. That is why the notion of (N — S) latitude asymmetry was introduced, rather than simply latitude asymmetry.

The results of corona structure qualitative analysis according to catalogue drawings are compiled in Table 1, where the character of asymmetry is indicated in the column 8. The first letter indicates in what hemisphere the corona structure is better developed as a whole, taking into account the polar radial systems and the high-latitude fan rays. The cases of feebly-expressed asymmetry are indicated in parentheses.

For certain cases, an E-W asymmetry was observed. It is linked with an irregular disposition of active formations of the Sun by latitude at time of eclipse observation and it has a random character.

It may be seen from Table 1 that the corona is more often characterized by a N — S asymmetry than by symmetry, and that no clearly-expressed cases of (S — N) asymmetry exist.

Presented are in Table 1 column 9 the results of qualitative comparison of Sun's activity in the Northern and Southern hemispheres according to synoptic maps. The Meudon [18] and Bugoslavskaya's [17] synoptic maps were then utilized. The asymmetry character is determined by facula activity which was estimated by the latter's surface. From the data brought out, it follows that the facula activity is more often better developed in the Southern hemisphere.

It should be noted that the latitude asymmetry was investigated earlier by Maunder [19], Svekhsvyatskiy [20], Bezrukova [21] and others on the basis of susnspot formation activity. The "Maunder's butterflys" show that the sunspot activity of the Southern hemisphere may cross the equator. At time of determination of Sun's rotation by sunspots (1879 — 1901), it was established that the smallest period does not correspond to the equator but to a somewhat more northerly zone [19]. Thus the character of coronal asymmetry is opposite to that of the photosphere- chromosphere.

For a more detailed investigation of the N — S asymmetry in the structure of the corona, we measured the extension of the Northern and Southern polar radial systems along the solar limb (Π_N and Π_S). The results of measurements are brought out in Table 1, from which it may be seen that the Northern radial system is more often better developed. No periodicity of any kind was noted, as this has been established from the spots [20]. The computed relation

$$\frac{1}{i}\sum\frac{\Pi_N}{\Pi_S} = 1.25 \pm 0.07 \ (i = 25),$$

corroborates with a great conclusiveness the presence in the corona structure of N — S asymmetry.

To explain the N — S asymmetry, one may assume that the aggregate magnetic field is disposed in the corona asymmetrically relative to solar equator plane. In order to corroborate such an assumption we measured separately the distances from the equator plane to the North and South poles of the "assumed" dipole (r_N, r_S).

It should be noted, that the parameters q and r are related to the aggregate field in the corona and to the field of the Sun, studied by photosphere observations. At the same time the conclusions of q variation with Φ does not provide the right to assert that the distances between the poles of Sun's magnetic dipole really vary.

In the columns 4 and 5 of Table 1 we brought out the values of r_N and r_S in solar radii ($R_\odot$) for 25 eclipses. From the comparison of such values it may be seen that r_N is more often $\geqslant r_S$. The computed relation

$$\frac{1}{i}\sum\frac{r_N}{r_S} = 1.11 \pm 0.03$$

corroborates the earlier made assumption. At the same time we may conclude that the symmetry plane of the magnetic dipole in the corona is somewhat raised to the North relative the solar equator plane.

In connection with the abive-expounded considerations the Grotrian and Kunzell results [22] acquire a great interest. These works bring out the mean yearly values of magnetic fluxes ($\int H\,ds$, where s is the surface element) of bipolar sunspot groups for 14 years of the period 1917 — 1949. The values of the fluxes are given separately for front-moving (p) and rear-moving (f) spots in each hemisphere. According to these data the following correlation were derived:

$$\frac{1}{i}\sum\frac{(p+f)_N}{(p+f)_S}=1.64\pm0.35 \text{ и } \frac{1}{i}\sum\frac{(p-f)_N}{(p-f)_S}=1.95\pm0.44,$$

where i = 12. The values of the relations are everywhere given with mean-square errors. As may be seen from the results of computations, the N — S asymmetry is characteristic for the magnetic activity of bipolar sunspot groups.

The investigation of the yearly variation of geomagnetic activity indicate that the seasonal maxima of activity are non-equivalent. Often the spring maximum is higher than the autumn maximum [23], but opposite cases are also observed [24]. Such an asymmetry in the yearly variation may apparently be explained by the effect of the asymmetric magnetic field in the corona on the corpuscular radiation of the Sun.

The N — S asymmetry established for the corona is apparently inherent to the total magnetic field of the Sun. If we add to this the observed fact of asymmetry of the Earth's magnetic field [25], we may assume that the property of asymmetry is characteristic for the magnetic fields of all the bodies of the solar system.

In conclusion, the author expresses his deep gratitude to S. K. Vsekhsvyatskiy for his valuable counsel and directives.

**** THE END ****

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